DoD Should Develop Deoxyribonucleic Acid Computing Technology

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Submitted by Captain J.F. Hudson Jr

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Major Stophel, CG 3

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Introduction

A Marine company has just arrived at its rally point. As they discuss the plan of attack, a sergeant notices the plants are changing colors around him. He immediately yells “gas, gas, gas” and the Marines quickly put on gas mask and protective suits. Plants changing colors to alarm a company that toxins are present, it can not be true. It is true, and this is one of many capabilities that “deoxyribonucleic acid (DNA) computing” can provide the Department of Defense (DOD). Technological superiority must continue to be a characteristic of the U.S. military and one of the foundations of our national military strategy. DoD should develop DNA computing technology for the services because it protects classified information, enhances medical functions, and provides battlefield advantages.

Technology behind DNA Computing

Leonard Adleman made the first DNA computation in 1994 by using his DNA computer to solve the “’traveling salesman’ mathematical problem -- how a salesman can visit a given number of cities without passing through any city twice.”[1] While this may not seem to be a huge mathematical problem for today’s computers to solve, it proved the point that DNA could be harnessed to compute. In addition, this problem at its core is

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[1] “DNA Computing Power-Could Be.” Wired News. 2003. http://www.wired.com/news/medtech/0,1286,60069,00.html.

not something that normal computers solve so easily. This problem is difficult for conventional computers to solve because it is a "non-deterministic polynomial time problem." Non-deterministic polynomial time problem problems are intractable with deterministic (conventional/serial) computers, but can be solved using non-deterministic (massively parallel) computers. A DNA computer is a type of non-deterministic computer.[2] In 1994, Adleman's DNA computer was "nothing more than test tubes of DNA-laden water, and yet this liquid has been coaxed to crunch algorithms and produce data."[3]

In order for a DNA computer to solve any problem or algorithm, nine operations need to be programmed into it:

1. Synthesis of a desired strand
2. Separation of the strands by length
3. Merging or pouring two test tubes into one to perform union
4. Extraction of those strands containing a desired pattern
5. Melting/annealing or the breaking/bonding of two DNA molecules with complementary sequences
6. Amplification to make copies of DNA strands
7. Cutting the DNA with restriction enzymes
8. Ligation of the DNA strands with complementary sticky ends using ligase
9. Detection or confirming the presence/absence of DNA in a given test tube[4]

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[2] Friedman Y. "DNA Based Computers." http://dna2z.com/dnacpu/dna1.html. A nondeterministic polynomial time problem allows for more than one outgoing transition for the same input. DNA, non-deterministic computing, computer can compute all pathways or branches in parallel.
[3] Wired News. 2003
[4] Kari, L. "DNA Computing: The Arrival Of Biological Mathematics." Unpublished manuscript. 1997

These operations took approximately one week to implement, while the problem could be solved by paper in about an hour. If the number of cities was increased to seventy, not even a supercomputer could solve it.

DNA computing harnesses power through parallel processing of multiple calculations at the same time: however, if the computation calls for only a single, complex calculation, DNA computers are not the best choice. After a decade of research and grants from NASA, the Pentagon, and other Federal Agencies, the technology is beginning to show progress, but it still has obstacles to overcome before being used on future battlefields.[5] Despite several hurdles in the advancement of DNA computing, the continued efforts of researchers have led to numerous application and application possibilities for DoD.

Protects Classified Information

In order to reduce the likelihood of classified information compromise DoD should develop DNA computing technology to be implemented into information assurance practices. Researchers from Princeton and Stanford universities "have outlined a way for a DNA computer to crack messages coded with the U.S. government's own Data Encryption Standard, which is used to protect a wide range of data, including telephone conversations on classified topics and data transmissions between banks and

[5] Wired News. 2003

the Federal Reserve."[6] They used DNA computing to perform complex computations and parallel testing of all 72 quadrillion encryption keys at the same time. In less than two hours, DNA computing was able to find the key and pass it to a resource for translation and exploitation. DoD should continue to build upon this exploitation using DNA computing in order to protect our classified information and gain advantages against U.S. enemies.

Enhances Medical Functions

In order to reduce battlefield casualties DoD should develop DNA computing technology to enhance current medical functions. Joanne Macdonald, PhD, a virologist at Columbia University's Department of Medicine, has led the way using DNA computing to distinguish accurately between virus strains like the West Nile virus. She suggests that "DNA computers could conceivably be implanted in the body to both diagnose and kill cancer cells or monitor and treat diabetes by dispensing insulin when needed."[7] DoD can use the implanted DNA computer to release corrective medications, transmit medical information, increase the body's ability to blood clot when a determined amount of blood is lost, or just monitor health. Scientists at the University of Portsmouth and the University of Alberta in

[6] "DNA Computing" *Universitiy Utara Malaysia*. 2003. http://azportal.uum.edu.my/portalai/indexDNA.cfm

[7] "West Nile Virus; DNA-based computer test targets West Nile Virus and other deadly diseases." *VirusWeekly*, November 7, 2006, 162. http://www.proquest.com/

Edmonton are researching and developing computer-controlled artificial limbs that use a DNA computing switch to move the limb and increasing the density of field dressings so that they clamp around a wound more effectively to prevent a death or blood loss during the “golden hour”.[8]

Provides Battlefield Advantages

In order to maintain military dominance DoD should develop DNA computing technology to be used on the battlefield. Nanoactuator is the ability of the cells within the body to create a continuous natural energy source/device. The energy device releases an electronic signal that can be sent to a computer and gets us a bridge between biological and silicon worlds.[9] Nanoactuator research has produced a plant whose leaf shape or flower color changes when a land mine is buried below it.[10] The roots have to be genetically altered to detect explosives traces in the soil and to communicate that information to the leaves or flowers.[11] Self-replication of plants or organisms would enable us to program them to detect toxins in the air and change colors to give warning of airborne

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[8] Firman, Keith, Dr., “A Biological Nanoactuator as a Molecular Switch for Biosensing.” 2007. URL://ftp.cordis.europa.eu/pub/nest/docs/5-nest-synthetic-080507.pdf.

[9] “Team Develops DNA Switch To Interface Living Organisms With Computers” *University of Portsmouth*. October 25, 2006. http://www.physorg.com/news81006721.html

[10] Firman, Keith, Dr.

[11] Anthes, Gary H. "Computation Comes To Life." *Computerworld,* February 28, 2005, 28. http://www.proquest.com/ Anthes, Gary H.

pathogens. Research is also being conducted to allow military pilots to use muscle twitching to pull an aircraft out of a high G-force banking before the pilot passes out. [12] DNA computing technology has unlimited potential and the ability to provide the U.S. military with a distinct advantage on the battlefield.

Obstacles Facing DNA Computing

Numerous factors have led to only minor improvements in harnessing the building blocks of life. These include failure to control and understand why DNA acts the way it does, accuracy of its calculations, and the amount of time required to extract results and finally, the theoretical aspect of DNA computing.

One of the major obstacles facing DNA computing is the failure to control and understand DNA. In order to utilize DNA effectively in a laboratory or DNA computer, one must control the circumstances of its use. While advances have been made since Adleman's first DNA computer, researchers are still faced with a daunting task:

> What these researchers are essentially trying to do is control, predict and understand life itself. So there's little wonder that their machines are decades away from being anything more than a neat laboratory trick. . . Biologists are only now grasping the basics of how and why DNA unzips, recombines and sends and receives information.[13]

How deterministic ordinary computers are compared with DNA computers is another factor in the inability to control and

[12] Firman, Keith, Dr.
[13] Wired News. 2003

understand DNA. DNA computers are probabilistic. For example, a sub-circuit may result in a “1” 89% of the time and a “0” the other 11%.[14] This leads to unreliability in DNA computer results.

Another factor contributing to the slow advancement of DNA computing is the accuracy of its calculations. DNA computers will never be accurate unless researchers address hydrolysis or the process of DNA molecules fracturing. DNA is the building block of life, and one undeniable fact of life is that one day it ends. Since DNA is in a constant state of decay, the DNA molecules used in DNA computers are subject to breaking down and causing inaccurate results.[15] Researchers must also strive to control the biological factors associated with DNA computing in a lab environment because “DNA does not always behave like it's expected to.”[16] Basically, it is a solution looking for a problem.

A third obstacle to the advancement of DNA computing is the amount of time required to extract results for ordinary computations. As mentioned earlier, early DNA computers were merely test tubes with DNA liquid. While “a single gram of dried DNA, about the size of a half-inch sugar cube, can hold as

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[14] Baum, E. “Will Future Computers Be Made of DNA.” 1996. http://www.techweb.com/winmag/library/1996/0696/06ana005.htm.
[15] Baum, E.
[16] Wired News. 2003

much information as a trillion compact discs”[17], the amount of time required harnessing results is days, if not weeks.

Finally, the last factor contributing to the slow advancement of DNA computing is the fact that DNA computing is considered to be in its fledgling stages. Mankind is years and years away from actually unlocking DNA computing true capabilities. Almost all work on DNA computing today is mostly theoretical.

Conclusion

While much of this technology is 10, 20, or even 30 years away, the potential future of DNA computing within DoD seems almost endless. DoD should develop DNA computing technology for the services because it protects classified information, enhances medical functions, and provides battlefield advantages. This will allow DoD to harness the parallel processing power of DNA computing for applicable military use. Otherwise, cracking sophisticated encryption messages, computer-controlled artificial limbs, and self-replication of plants or organisms may never advance or become reality. According to MIT researcher Thomas Knight, "All powerful technologies are dangerous, and we are creating a powerful technology and our

[17] Wired News. 2003

best defense is our ability to do it faster, better, and cheaper than anyone else."[18]

1576 words

[18] Anthes, Gary H.

Bibliography

Adleman, Leonard. Molecular Computation of Solutions to Combinatorial Problems. Science, 266:1021-1024. 1994

Anthes, Gary H. "Computation Comes To Life." *Computerworld,* February 28, 2005, 28. http://www.proquest.com/ (accessed December 17, 2007).

Baum, E. “Will Future Computers Be Made of DNA.” 1996. http://www.techweb.com/winmag/library/1996/0696/06ana005.htm. (accessed December 17, 2007).

Bonsor, Kevin. *"How DNA Computers Will Work"*. November 17, 2000. http://electronics.howstuffworks.com/dna-computer.htm (accessed December 17, 2007).

Department of Molecular Science, University Southern California, http://www.usc.edu/dept/molecular-science/main.html. (accessed December 17, 2007).

“DNA Computing“ *Universitiy Utara Malaysia*. 2003. http://azportal.uum.edu.my/portalai/indexDNA.cfm (accessed December 17, 2007).

“DNA Computing Power-Could Be.” Wired News. 2003. http://www.wired.com/news/medtech/0,1286,60069,00.html. (accessed December 17, 2007).

"DNA Synthesized On Silicon Chip." *Chemical & Engineering News*, February 24, 2002, 32. http://www.proquest.com/ (accessed December 17, 2007).

Firman, Keith, Dr. “A Biological Nanoactuator as a Molecular Switch for Biosensing.” 2007. URL://ftp.cordis.europa.eu/pub/nest/docs/5-nest-synthetic-080507.pdf. (accessed 14 December 2007).

Friedman Y. “DNA Based Computers.” http://dna2z.com/dnacpu/dna1.html. (accessed December 17, 2007).

Kari, L. “DNA Computing: The Arrival Of Biological Mathematics.” Unpublished manuscript. 1997

Mankin E. (1995). “Supercomputing with DNA.” http://uscnews.usc.edu/detail.php?recordnum=1408. (accessed December 17, 2007).

Paulson, Linda Dailey. "DNA Computer Is a Tic-Tac-Toe Champ." *Computer,* December 1, 2006, 24-25. http://www.proquest.com/(accessed December 17, 2007).

"Revolutionary DNA computing device." *R & D*, April 1, 2003, 15. http://www.proquest.com/ (accessed December 17, 2007).

Srivastava, Siddharth. “Fear Not Traveling Salesmen, DNA Computing is Here to Save the Day.*” Journal of Young Investigators.* Issue 2, September 2003 (accessed December 17, 2007).

“Team Develops DNA Switch To Interface Living Organisms With Computers” *University of Portsmouth*. October 25, 2006. http://www.physorg.com/news81006721.html (accessed December 17, 2007).

“The Future of Silicon May Be Carbon”. Wired News. 1997. http://www.wired.com/news/technology/0,1282,2132,00.html. (accessed December 17, 2007).

Tom Simonite. "DNA processors cash in on silicon's weaknesses." *New Scientist*, August 5, 2006, 24-25. http://www.proquest.com/ (accessed December 17, 2007).

Tomar, Suramya. “DNA Computers.” http://tech.suramya.com/dna_computing/(accessed December 17, 2007).

Toshinori Munakata. "Beyond Silicon: New Computng Paradigms." *Association for Computing Machinery. Communications of the ACM* 50, no. 9(September 1, 2007): 30-34. http://www.proquest.com/ (accessed December 17, 2007).

"West Nile Virus; DNA-based computer test targets West Nile Virus and other deadly diseases." *Virus Weekly*, November 7, 2006, 162. http://www.proquest.com/ (accessed December 17, 2007).

Yan, Hao, Zhang, Xiaoping, Shen, Zhiyong and Seeman, Nadrian C. “A Robust DNA Mechanical Device Controlled By Hybridization Topology.”